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ART. I.—*Neurotomy.* By S. WEIR MITCHELL, M.D., of Philadelphia. *With an Examination of the Regenerated Nerves, and Notes upon Neural Repair,* by R. M. BERTOLET, M.D., Pathologist to the Philadelphia Hospital. (With ten wood-cuts.)

I HAVE long been of the opinion that many of the failures to relieve pain permanently by nerve sections are due to the fact that very often, and more speedily than has been generally believed, the nerves in man repair damages, and reconnect with the centres the parts which it was desired to isolate. To settle this question, I have collated one hundred and twenty cases of nerve sections and exsections. But few of these are well reported, and the surgeons seem to have been usually satisfied with stating only the immediate results. One was cut because of chorea, the rest to relieve neuralgia.

The immediate results were total relief in ninety-six cases. In eight of these pain, great or less, came back within three weeks, a period probably too brief for nerve repair. There must, therefore, be some reason why a section thus eases pain without curing it permanently, and the cause may lie in some alteration which the shock of an operation effects in the sensorium; for in at least one case where there was disease of one nerve (median), section of another, the musculo-spiral, caused total relief for eight days only. The loss of a tooth will also arrest for a time in some cases neuralgia of the supra-orbital nerve, due to an intracranial lesion, and I know of many cases in which firm pressure on one branch of the fifth nerve relieves or arrests pain in a remote branch of the same nerve.

Twenty-five cases were still well at the close of a year, but of these five relapsed within two years; but of the ninety-six, twenty-seven had their neuralgia again within periods varying from one month to eighteen. As to the rest, the details are incomplete, and we learn nothing of their future. In four, permanent relief came of secondary operations.

Surgeons have often hesitated to admit that a large proportion of these failures are due to regeneration of the cut nerve; but when we view these statistics in the clear light cast upon them by the three cases of well-proved regeneration which this paper reports, I think it will be no longer doubtful that a large percentage of failures must be laid to this cause. As yet we do not know how soon a nerve in man may repair itself, but in my case this took place within six months, and in Dr. Hodge's cases in a few weeks in one and within a year in the other. The best test of repair is not merely the return of feeling in areas where it was lessened or lost owing to section, for it is now sure that in some way, by terminal or current anastomoses, and by direction of attention to the regions of dulled sensation, this may improve irrespective of nerve repair, while if palsied muscles recover power, there is no conceivable mode in which this could occur save by restoration of the cut nerve. To insure permanent relief, I suggest that in all nerve divisions as much as possible of the nerve should be taken away, and the digital end doubled on itself and secured in this position. The cautery has been used, with the idea of making reunion difficult, but a proper conception of the methods of repair would have taught the surgeon that there was no gain in this measure. Perhaps the safest plan would be to turn the digital end of the nerve aside, and bury it in the body of an adjoining muscle. The following cases illustrate the position here assumed.

CASE I. In the July number of this Journal for 1874, I reported a case of section of the median nerve. To it I beg to refer the reader for full details. The original injury was in the median territory of the right palm, and for relief of neuralgia thence arising. Dr. John H. Brinton divided, at my request, the median nerve in the forearm. This operation removed three-fourths of an inch of nerve, and as the lower end of the cut nerve was doubled on itself, and secured by a thread to prevent reunion, the interval betwixt the nerve ends became by measure 2½ inches.

On reading the case the reader will observe that in November, 1871, the justly distinguished surgeon to the King of Italy, Dr. Sapolini, for reasons which seem to me to have been ample, cut down on the musculo-spiral nerve in Miss T.'s arm, and removed one inch of it. This operation eased the median pain, which, however, came back in eight days suddenly. The section caused remarkable atrophy of the extensor group in the forearm, with entire loss of power to extend the wrist, and to use the common extensor of the fingers. The loss of sensation in the hand was certainly but small, was indeed so slight as to amaze Miss T.

And now comes the new point of interest in this most instructive case. As early as April, 1872, certainly within *six months* after section, Miss T. observed a notable enlargement of the wasted extensors, and at the same time a slight power to extend the wrist and fingers. In June, 1872, she could fully extend the hand to a level with the arm, but not beyond this. In the paper I quote I said that in February, 1873, she could not extend the wrist; it should have been—fully extend. At this date there was normal touch in all of the radial region in the hand; that is, a feather touch was felt everywhere, and was correctly referred.

The median section was made March 2, 1873. I saw Miss T. again in the summer of 1874, about two years and seven months after Dr. Sapolini's section of the musculo-spiral. During 1873 and 1874, the whole of the function of the extensor group in the forearm returned; no action was missing, and there was nearly normal power, that is, in the winter of 1874. Miss T. could perfectly extend the hand, and she could do this with a close approach to normal force, but could not keep up extension as long as she could with the left limb. It was, I believe, in January, 1874, that she began to have pain in the line of Dr. Sapolini's incision over the musculo-spiral nerve, and soon after excessive pain in the radial region of the back of the hand. This was accompanied by very great swelling with redness and heat, so that it was again and again supposed an abscess might form. This false phlegmon went and came; went with lessened pain, and came anew with great increase of torment. At length the use of leeches followed by ice to the scar did away with the swelling in the hand, but the pain in varying amount was never quite absent.

I had become of course fully satisfied that reunion of this nerve had taken place, and it seemed to me probable that the new trouble lay in this reconstructed tissue. I think now that a little reflection upon the mode of re-union of nerves might have led me to a different view, but the situation was so novel as to offer no clinical precedent. A number of measures, mild or not, were tried, and vainly tried, to ease the pain. When at last Miss T. was in grave danger of constant habitual resort to narcotics, I yielded to her wish to have cut anew this reunited nerve, my decision being influenced by the failure of other means of relief, and being made more easy by the fact that the muscles within the control of the musculo-spiral nerve were again becoming feeble, so that it seemed likely that before long not only might there be an entire palsy of this nerve, but also that the pains might become permanent. Accordingly, after consultation with Drs. J. H. Brinton and Keen, the former cut down through Dr. Sapolini's old incision and once more divided the nerve.

We found the new nerve, as presented in the accompanying wood-cut, Fig. 1, running between two buttons of neuro-fibrous tissue which marked above and below the site of the two ends of the divided nerve. Dr. Brinton removed the whole just as it is figured and described by Dr. Bertolet.

The result of this operation was a partial relief of pain, but within a few days the ease increased, until at present, June, 1875, there is no pain at all.

Fig. 1.

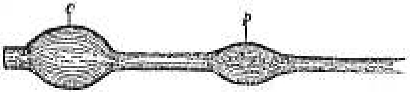


Fig. 1. Portion of musculo-spiral removed from Miss T.'s arm. Length nearly three inches. *c*, central, *p*, peripheral swelling. The distance between *c* and *p*, the regenerated portion, is one inch.

As to whether or not the future will bring back to this much-suffering woman a renewal of torment I cannot say. If there be no new pain within a year I shall feel safe, and at least, I am reasonably sure that there can now be no re-growth of the nerve, since both the length of the portion taken away (three inches) and the situation around the bone seem to make a reunion most unlikely. Apart, however, from the therapeutics of the case, it presents characters of such interest as set it aside from most other cases of neurotomy, and give to its physiological aspects a value so novel that I have thought it proper to discuss these at length and to ask of Dr. Bertolet the most careful study of its anatomical peculiarities.

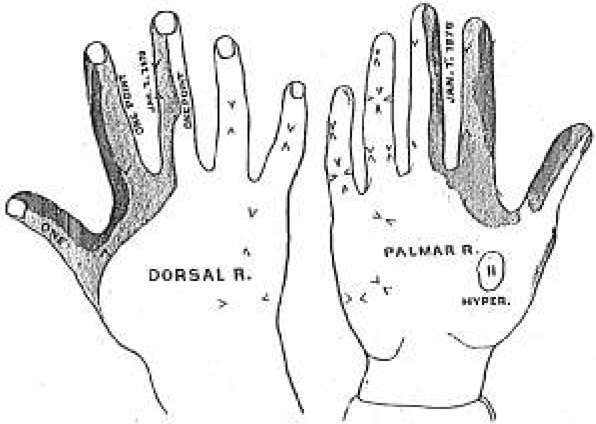
There have been many cases of nerve sections in man by accident or design where the repair of the nerve has been suspected or proven by well marked return of physiological power, but the cases in which there has been occasion to examine the cut nerve after death are exceptionally rare. So far indeed as I can learn, and I shall be glad to be corrected if I be in error, this present case is the first one in which a nerve once cut has after repair been cut a second time so as to remove the restored portion. In this instance repair must have begun in a few months, or rather actually within six months there was available neural connection between the two nerve ends, and partial repair of wasted muscles. When I saw her first this process was still going on, and the muscles were recovering power. Before we cut the median, and since, I frequently faradized the musculo-spiral nerve above the section and threw the extensors into play. When at the second operation the nerve was laid bare, I repeated this test with like success, putting the conductors on the exposed nerve itself. Of the condition of the new nerve and of the terminal buttons I shall leave Dr. Bertolet to speak, remarking only that there were no pathological conditions in the new nerve to account surely for the pain, and that, if of peripheral birth, it must be referred to the state of the terminal buttons.

We next come to the point of most interest in this case, which has decided so many questions. Some of my readers will recall the positive manner in which I have stated elsewhere that we know as yet but little about the surface distribution of nerves. The present case yet further illustrates my position, and is, in fact, a clear and perfectly satisfactory proof that the facts which Arloing and Tripier proved to exist in the *dog, are no less true of man*. These observers have shown that in dogs any single nerve left uncut will leave the paw of the dog more or less sensitive in its every part. This conclusion I have always felt nearly sure would be found to apply to man. In the present case there was cut the median at the middle arm, leaving above the point cut the muscular and anterior interosseous branches, but cutting off the origin of the palmar-cutaneous. Then later the musculo-spiral was cut high up, so that this hand has left only the ulnar and the few filaments which come to it from the musculo-cutaneous and the internal cutaneous. In my previous account of the case (*op. cit.*) I described with extreme care the amount of loss of feeling from section of the median nerve. To this I refer the reader for full details, with this comment: Two weeks after section of the median there were large regions of the hand into which a needle could be thrust deeply without causing pain. After section of the musculo-spiral nerve

I waited some three or four weeks, and then examined the hand as to its loss of sensation. I found, in the first place, what did not greatly surprise me, that there was a notable preservation of feeling, but I found, also, that in the median nerve territory there had been, in the long period which had elapsed since it was isolated, an improvement so great that nowhere was there a place into which you could thrust a needle deeply without causing pain. Sense of pain was lessened, but not lost, as it had once been. This recovery might have been considered due to restoration of the cut median, despite our great care to prevent it; for we not only took out a piece, but so disposed of the question by doubling the lower nerve end on itself as to leave it thus with an interspace of 2½ inches. Restoration then was unlikely, and, besides, had it taken place, the median muscles in the hand would have grown anew, and responded to the will and to the battery—but they did not; and so we must seek other theories for an explanation of this astonishing change.

And now to look at the whole amount of sensory loss in this hand, to which ran alone the filaments of the internal cutaneous, musculo-cutaneous, and the ulnar. By all the old rules of belief, we should have found feeling annihilated somewhere, but really it is nowhere absent. I give below two diagrams of the palm and dorsum, made by Dr. Neff, resident physician at

Fig. 2. Fig. 3.



Figs. 2 and 3 Light lines indicate loss of sensation to feather touch; dark lines, impairment to touch of needle. H, Fig 3, a small space where a touch is said to cause pricking sensations.

the Infirmary for Nervous Disease, Philadelphia. Dr. Neff has ingeniously represented the facts on the diagram, so as to save me a large amount of verbal explanation. Dr. Neff's diagrams have been carefully tested by re-examinations made by my colleague, Dr. Geo. Gerhard, and by me; and I mention this because to study and report accurately the true state of sensation as to touch and pain is in itself no easy task. At the Infirmary for Nervous Disease we now resort to these tests: the needle, to determine surface feeling, and deeper sensibility; the touch of a feather tip for touch and localizing capacity; and, lastly, the compass points for delicate appreciation of slightest disturbances of tract.

Sensation as tested with the Compass Points.

RIGHT HAND.	LEFT HAND.
Index and Middle Fingers.	
Radial side. Points cannot be distinguished as two.	Radial side. Normal; the distance at which the compass points are recognized as two, is 5 lines.
Ulnar surface. The points are felt as two at the distance of 1½ inches.	Ulnar surface. Normal (4 lines).
Dorsal surface. Compass points are not felt as two.	Dorsal surface. Normal, or nearly so, as at the distance of 7 lines two points are felt.
Thumb.	
Only one point is distinguished.	Normal.
Ring and Little Fingers.	
Slight loss compared with left hand. Points felt at ⅜ inch.	Compass points felt at ⅛ of an inch.

Some loss on the dorsal surface of right hand, the points being recognized as two at the distance of ¾ of an inch; whereas on the left dorsum they are distinguished at the distance of ¼ of an inch.

For the exact sites of these comparative tests, see arrow-heads on the diagrams.

From the above it would appear that there is some slight loss of sensation extending over the whole of the right hand—not quite as marked, however, in the ulnar distribution as elsewhere.

Dec. 30, 1875, I re-examined this hand. While she has still in all parts of it sense of pain to a needle prick, she has now more power than ever to feel a touch. If it be a little rough, or the pencil-tip or feather be moved a little, she feels it, after a moment, in every part of the entire hand. On the median side of the palmar face of the third finger the compass points are felt as two when three and a half lines apart; whilst last year, at this place, only one point could ever be recognized. But touch on the palmar face of the second finger is erroneously referred to the palm or the thumb; and touch on the thumb is felt as if it were on the second finger. In some other spots of the median territory the references are incorrect by half an inch, or the recognition is tardy. At the finger-ends of the first, second, and third fingers back and front, the touch is felt as if it prickled. To cut the nails gives pain, and while touch, if not too light—and a needle prick always—can be felt throughout the radial region, nearly everywhere in it is touch felt as an annoyance. Of late, also, there has been a dull pain referred to the dorsum of the hand.

While the sense of pain and touch is so much bettered, the appreciation of temperature is almost lost except for extreme heat; ice being felt at first as heat or pain, and only in some places and after longer contact as cold; warmth and coolness, in slight degrees of intensity, are unfelt as such.

She is aware of the position of the fingers when her eyes are closed, and the parts are actively or passively moved. As to muscular movement, Miss T. can slowly but perfectly close all the four fingers in flexion, and can more slowly but entirely open them all in extension. The thumb has scarce any motion. The thumb muscles are greatly wasted, and the ulnar adductor, the only one intact, is too feeble to be of use alone. The extension of the fingers is limited to the second and third phalanges, and is ready and quicker in the fourth and fifth digits, but slower in the second and third.

No form of electrical current direct or indirect stirred the median thumb muscles of the hand, and for this and other reasons stated above, I cannot believe that the median nerve has been regenerated, so that we are forced to look to the coarse and fine anastomoses, whether current or terminal, and to recurrent fibres of the median and radial to explain the gradual gain in sensory power. At present our anatomy is incompetent to give us full help—as any anatomist knows who will read what I have said above and then try to point out the anastomoses which are to account for the gain—but whencesoever this comes, it comes slowly, and we learn by degrees to use the new channels.

CASE II. *Dr. Hodge's Case of Neurotomy, Digital Branch of Ulnar Nerve, and Digital Branch of Median Nerve, 4th Finger of Left Hand.* Notes by Dr. Hodge.—In April, 1874, I excised about one inch of the digital branch of ulnar nerve on the 4th finger of the left hand of Mrs. M., a patient of Dr. George A. Rex, on account of intense pain over the ulnar side of the dorsal region of the last phalanx of this finger. During the last four years this pain had caused great suffering and sleeplessness; but it had existed with more or less intensity for about 15 years. She believed the cause to be carrying a bucket filled with water. This produced at the time a feeling of numbness in the finger, which remained for two or three days, but after this had passed away there was no inconvenience for several months. When the cold weather came the pain began, and then continued at all seasons of the year.

The nerve was divided at about the middle of the second phalanx, and about one inch removed, the dissection being carried down to the smallest filament visible. The operation was followed by temporary relief. The pain however returned, and soon regained all of its old severity. After having tried for 18 months many plans to obtain relief, Dr. Rex again sent her to me. Upon examination, I found that the area of pain had increased, and had extended more over the back of the finger, and that the sensibility to touch had returned in the parts supplied by the divided nerve. In my opinion the nerve had reunited, and I proposed to again excise a portion of the digital branch of the ulnar nerve, and if possible turn back the distal end in its course so as to prevent reunion, and to extend the operation by excising a portion of the digital branch of the median nerve on the other side of the finger, and to dissect away and remove all the skin of the painful region, and, as this involved a part of the matrix of the nail, to remove also the nail and cauterize the matrix.

The operation was done Nov. 27th, 1875. I found the ulnar nerve reunited with a bulb on the proximal portion, and the other extremity adherent to and closely incorporated with the scar of the former operation. The accompanying drawing (Fig. 4) represents the appearance of the nerve. After the wounds had healed, Dr. Rex carefully examined the areas of sensibility on both dorsal and palmar surfaces. The results are shown in the accompanying drawings, Figs. 5 and 6. The patient, thus far, January 14th, remains free from pain.

Fig. 4.

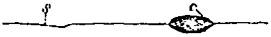


Fig. 4. Dr. Hodge's case of neurotomy of ulnar branch of fourth finger of left hand. *c*, central neuromatous swelling; *s*, distal end adherent to the scar.

Fig. 5.

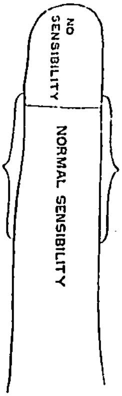
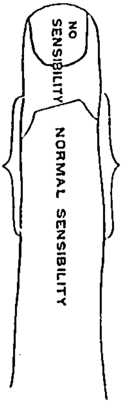


Fig. 6.



Figs. 5, Palmar surface, and 6, Dorsal surface. Extent of portion excised, 1¼ inch. The brackets indicate the positions of excised nerves.

CASE III. On Dec. 5th, 1874, says Dr. Hodge, I removed about two inches of the radial nerve in the back of the forearm, after it comes out from under the tendon of the supinator longus. The operation was done on account of long-continued and persistent pain in the back of the hand accompanied at times with great redness and swelling. The patient was fifteen years of age. After the operation she was perfectly free from pain, and had no sensation in that part when touched. In about six weeks the pain gradually began to return; a few weeks later the tactile sensation also returned. The pain grew worse and became as severe as at any time before the operation. Nothing gave relief, although every means was employed in consultation with Dr. S. Weir Mitchell. As the tactile sensation had returned as well as the pain, it was evident to us both that the nerve had probably reunited, and that the pain was not merely subjective and referred to the old part. Therefore, on October 20th, I repeated the operation, and found the nerve, as expected, reunited, with the bulbs of reformation as in Fig. 7. The distance between the bulbs was one inch and a quarter. At this last operation I removed three inches of the nerve and turned back the ends of the distal extremity so as to form a loop, and thus endeavoured to prevent another restoration. This operation, as well as the preceding, was done entirely outside of the deep fascia, and therefore no motor filaments were removed, and no power in motion of the hand or fingers is wanting, nothing being lost but sensation. The areas of sensibility are shown in the accompanying drawing by Mr. Goldsborough from careful examination made two weeks after the operation, and repeatedly tested by Dr. Hodge himself. The parts described as having lost sensation (marked by darker lines) were insensible to any needle prick—the region of lessened sensation (marked by lighter lines) was insensible to a very light touch, or else felt it doubtfully, or slowly, or misplaced it, but could feel the needle. The sensation in the fingers beyond the lines given was not then studied with compass points, but it as well as the rest of the dorsum was most carefully tested by light touch and by comparison found to be not worse than in the sound hand. After the first section the lack of feeling existed further out on the fingers than after the latter section, the results of which are seen in Fig. 8.

Fig. 7.

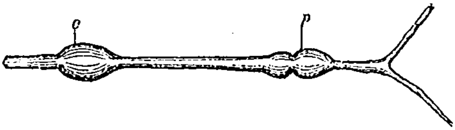


Fig. 7. Radial nerve in Dr. Hodge's case. *c*, central, *p*, peripheral swelling. Entire length of excised portion three inches. Distance between *c* and *p* one and one-fourth inch.

Fig. 8.

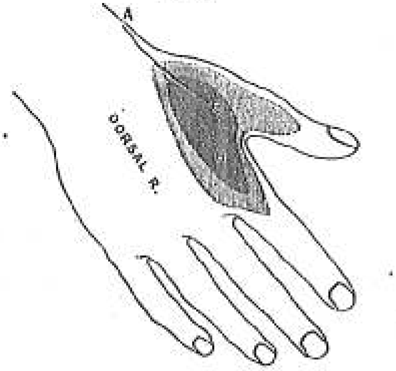


Fig. 8. All that portion of radial nerve between A and B and A and C was removed.

On the 3d day the wound was healed, save for a small spot at the wrist which became an irritable ulcer, and has now extended an inch up the line of wound, Jan. 19, 1876.[1] On the 8th day after operation, an herpetic eruption broke out on the radial side of the healed incision—high up—and two days later on the ulnar side. The vesicles were close to the edge of the scar, and there was not much pain with them.

Recently, the whole region of lost and lessened feeling has become hyperæsthetic or perhaps more properly hyperalgesic, just as happened in the case of Miss T., reported by Dr. Mitchell.

Jan. 20. The child was seen in consultation with Dr. Mitchell. At this time it was found, that, on every part of the region noted in the map —of Oct. 20, 1875—as insensible or dulled as to sensation, there was feeling either to the needle or to touch, and that all contact was felt as an unpleasant tingling, touch being felt as pain and touch. The touch beyond the regions marked in the plate as deficient was absolutely normal to the æsthesiometer.

The three cases above related, two of which I owe to the kindness of Dr. Hodge, seem to me full of value to the surgeon and the physiologist. They all show the slightness of our knowledge as to surface nerve anatomy, and indicate how curiously it may vary. Then, too, they prove how difficult it is, especially in young people, to prevent reunion of cut nerves, and how perfect may be that repair.

Two of them seem to me to make it almost sure that by some other paths than restored nerve-tubes sensation may be vastly improved in the territory we have sought to isolate, because it gains distinctness in cases where no muscular function returns, and where, therefore, repair could hardly have taken place.

These cases add, also, a new clinical feature in the fact that the return of sensation through other than direct channels is accompanied by a hyperalgesic condition.

Lastly, in cases of renewed sensory function after nerve-section, the various forms of sensation do not all alike recover, but sometimes the sense of pain and touch, being nearly normal, that of temperature remains imperfect, not merely in degree, but, so to speak, in kind; as also does touch in certain cases where it is felt as that, and also as pain. These facts seem to me altogether inconsistent with the popular medical view which holds to the idea of multiple nerve-fibres for all the forms of sensory impressions.

The excised portions of nerve, in all three of the above cases, were examined by Dr. Bertolet, whose reports we subjoin:—

The excised portion of the musculo-spiral nerve, Dr. Mitchell's Case I., was frozen shortly after its removal, and fresh sections obtained; some of these were coloured in a solution of terchloride of gold, others in perosmic acid. Subsequently the specimen was placed in a hardening solution, and very satisfactory cuts were also secured by this process.

The microscopic examination shows the central enlargement to consist almost entirely of double contoured nerve fibres, which interlace and cross one another in every possible direction, as represented in Fig. 9. The primitive nerve fibres lying in the central end do not appear to be arranged in regular nerve bundles, but are more or less widely separated by the development of connective tissue. Towards the outer margins of the growth this increase of fibrous connective tissue becomes more decided, and even the perineurium seems to be slightly hypertrophied. This central nodule may, therefore, be said to consist of numerous nerve fibres and moderately increased connective tissue; the former, differing in no wise from those of an ordinary healthy nerve trunk, except in their irregular interlacing arrangement, present each a sharply-defined axis cylinder surrounded by the white substance and sheath of Schwann (neurilemma). At not a few points the nuclei of the nerve sheaths are more numerous than usual.

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[1] On the 26th of January the ulcer had entirely healed.

Fig. 9.

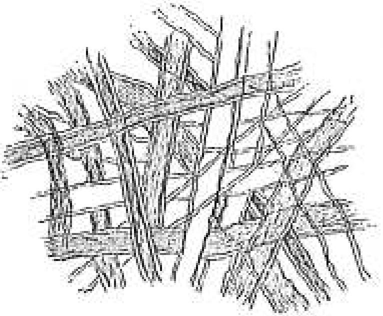

Fig. 9. Longitudinal section of proximal neuromatous swelling. Miss T.'s musculo-spiral nerve.—*Hartnack*, Oc. 3, Ob. 7.

The button-like swelling upon the peripheral end, as will be seen in Fig. 1, p. 323, is smaller than that upon the proximal end, yet it presents essentially the same histological features. In it the primitive nerve fibres are oftener arranged in parallel rows, so that it is possible to follow an individual primitive nerve fibre for a considerable distance up into the regenerated portion of the nerve trunk.

Horizontal and vertical sections of the intermediate portion of the nerve between the neuromatous swellings are indistinguishable from those obtained from a perfectly normal nerve; thus showing how complete has been the regeneration of the excised part. Even a multiplicity of the neurilemma nuclei is extremely doubtful, although precisely the same methods of staining with carmine, etc., as had been resorted to in the other cuts, were employed to clearly develop them. The primitive nerve fibres throughout the entire length of the intermediate portion pursue a parallel course and are arranged in nerve bundles and fasciculi.

The cicatricial neuromatas in this specimen do not differ from those which are formed after the decision or excision of a large nerve trunk from the lower animals. The central swelling, in accordance with the invariable rule, is also here the larger. Similar growths often occur upon the nerve stump after amputation, but frequently the proliferation of connective tissue so far predominates in them, that they can no longer be designated as true neuromatas. In Miss T.'s nerve, however, the tumours are so largely made up of newly-formed nerve fibres as to fully warrant such a classification. Unfortunately in this and the following cases of Dr. Hodge too long a period has elapsed since the primary operation, and too few traces remain to permit any positive conclusions as to the precise mode in which the regeneration has taken place. Still the evident increase by segmentation in the nuclei of the neurilemma, traces of which are yet noticeable in both the central and peripheral ends, leaves little room for doubt but that also in the human subject these nuclei are the principal factors in the reproduction of divided nerves. Although the reunion of nerves seems to take place under the most adverse circumstances, and though our methods of studying nerve structures have been so greatly improved, yet the comparative infrequency of the operation of excision, and the utter impossibility of watching the various phases of the reparative process, will, no doubt, compel us for a much longer time to resort to comparative experiments upon animals. Further, there is every reason for believing that the natural regenerative processes in man and certain animals are identical throughout. Numerous as the observations and experiments upon this point are, there is, nevertheless, such a bewildering conflict of authority as to render fresh investigations desirable.

With a view to ascertain the correctness of some of the statements made, I have divided in several kittens the ischiatic nerve, ligated it in others, and in one excised nearly half an inch of this nerve. Without entering into any minuter details of these experiments, I will here only briefly mention the histological changes which I observed in the divided nerves. The results are merely confirmatory of what has already been noted by others. The power of nerve regeneration is dependent upon the health, age of the individual, etc., being much greater in the young. Those interested will find young cats, on account of the limited amount of connective tissue in their nerve trunks, very well adapted for the study of the degenerative and regenerative processes taking place in divided nerves.

In a few hours already after the division of the nerve, both the nerve stumps become more or less swollen, grayish-red or yellowish in colour, and slightly transparent in appearance. The causes of these manifestations are seen in the engorgement and thrombosis of the divided or injured vessels of the nerve trunk, and in the saturation of the primitive fibres with transuded serum. Coagulation of the myeline speedily follows. It becomes cloudy and breaks up into concentrically laminated fragments, fat globules, and granular masses of detritus. These degenerated lumps of myeline escape in considerable quantity from the retracting nerve sheaths, and accumulate around the stumps. The primitive sheaths are often distended at points to twice their normal diameter, while at the same or later period the axis-cylinder appears swollen and soon begins to disappear entirely, so that in the advanced stages of the degenerative processes even the gold solution fails to render it visible.

These changes attain their maximum intensity in the immediate vicinity of the trauma, and extend but a very short distance along the central end, while it is correctly stated by Benecke[1] and Hertz[2] to extend uniformly throughout the peripheral end of the nerve to its ultimate branches.

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[1] Ueber die Histologischen Vorgange in durchschnittenen Nerven. Virch. Archiv, Bd. 55, S. 496.

[2] Ueber Degeneration und Regeneration durchschnittener Nerven. Virch. Archiv, Bd. 46, S. 257.

The first traces of the regeneration begin to show themselves a few days after the ligation or division of the nerve, while the degenerative changes mentioned above are still in progress. The commencement of the regenerative changes, although much disputed, must certainly be ascribed to the active proliferation of the nuclei of the neurilemma. They multiply by segmentation, are arranged in rows, and surrounded by a layer of protoplasm, have roundish, oval, and even spindle forms. This proliferation is seen in the central swelling and throughout (Benecke) the peripheral end of the nerve. The increased nuclei elongate into long spindles, while, at the same time, the medullary substance disappears, probably serving as pabulum for the cells. Gradually as the regeneration progresses these spindle-shaped nuclei, in both the ends and cicatrix, send out long filamentous protoplasmic processes, which unite with one another and widen into narrow bands. These single contoured fibres are next surrounded by a second, sharply-defined, glittering contour. As the reparative process approaches completion these short cylinders gradually blend into one continuous medullary sheath. During these final changes a greater portion of the proliferated nuclei disappears, and very few remain as the permanent nuclei of the neurilemma. The nerve sheath being next filled out at all points with medullary substance around the axis-cylinder, present a uniform width throughout, and the regenerative process is now completed.

Fig. 10.

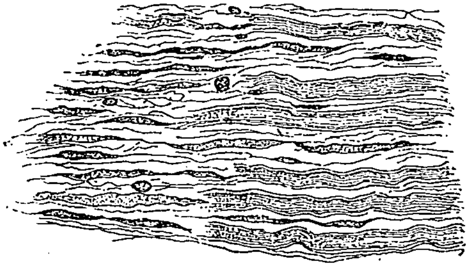

Fig. 10 represents a section at the point of union of the intermediate portion with the central end. It was removed from a cat six weeks after the excision. Many of the spindle cells, it will be seen, have already, in this short period, coalesced into long single contoured bundles.—*Hartnack*, Oc. 3, Ob. 7.

The reunion of the separated nerve ends in cases of excision does not take place by the primitive fibres of the central and peripheral ends simply growing towards each other, as claimed by Schiff,[1] Waller,[2] Neumann,[3] and others, but is brought about by the coalescence of spindle cells arranged in rows in the intermediate cicatricial portion, which, at the same time, unite with the primitive fibres of both ends. Virchow,[1] Hjelt,[2] Benecke,[3] Hertz,[4] and many others admit the latter mode of development of the new nerve fibres in the cicatrix; a process analogous to the embryonal formation of nerves, which can be so readily observed in the caudal appendages of the triton and tadpole.

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[1] Zeitschr. f. wiss. Zool., Bd. vii., S. 338.

[2] Nouvelles Observations sur la Régénération des Nerfs. Comp. Rend., t. 34.

[3] Arch. de Heilkunde, 1868, S. 193.

Hertz has lately concluded that the migratory white blood corpuscles are the source of most of the spindle cells and newly-formed nerve fibres. It is not made evident how the blood corpuscles enter the nerve sheath, nor is such a theory needed in the presence of the unmistakable proliferation of the neurilemma nuclei.

Interesting as are many of the other views advanced in connection with the regeneration of divided nerves, I shall not attempt to enumerate them here. Those that have been advanced are such as the experimental observations have fully confirmed.

Through the kindness of Dr. Hodge I have recently had the opportunity of studying the two cases of nerve regeneration in the human subject appended to Dr. Mitchell's case. The results obtained are so nearly those of the preceding example that I shall not here detail the histological appearances; they are essentially identical.

ART. II.—*Ligations of Large Arteries at the Pennsylvania Hospital between the years 1868 and 1876, with a table of all the Large Arteries which have been Tied in that Institution, including the completed history of a Case of Ligation of the Left Internal Iliac Artery, with Remarks, etc.* By THOMAS G. MORTON, M.D., one of the Attending Surgeons to the Hospital, etc.

IN the Pennsylvania Hospital Reports for 1868, I published a review of all the ligations of large arteries occurring in this Institution between the years 1835 and 1868; during which period only seventeen such operations were performed; the subclavian had been tied once, the common carotid five times, the common iliac once, the internal iliac once, the external iliac three times, and the femoral artery on six occasions. Of these ligations, three of the carotid and one of the external iliac proved fatal.

Since 1868, among the cases where occlusion of vessels by the ligature was resorted to, twelve only are recorded in which arteries of magnitude were involved; these were principally in the treatment of hemorrhage, aneurisms, and elephantiasis Arabum. Four of the ligations were upon the common carotid, in three of which the patients perished; the subclavian was tied once, with a fatal issue; the axillary and brachial arteries were

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[1] Die krankhafter Geschwulste, Bd. iii., S. 247.

[2] Ueber die Regeneration der Nerven. Virch. Archiv, Bd. xix., S. 352.

[3] Virchow's Arch., Bd. 55, S. 496.

[4] Virchow's Arch., vi., S. 257.